LUMINQ26: Additively Manufactured Colloidal Quantum Dot Embedded Waveguides for Wavelength-Based Thermal Sensing

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Introduction

Why flexible optical thermal sensors useful:

- Used for system actuation
- Non-destructive evaluation (NDE) applications

Current Solutions:

- High instrumentation cost
- Low flexibility
- Limited scalability & deployment

Our Solution: An additively manufactured (AM) core-shell colloidal quantum dot (CQD) waveguide for thermal sensing using CQD emission wavelengths as the sensing metric. , improving resilience to variations in optical intensity caused by environmental effects and photodegradation.

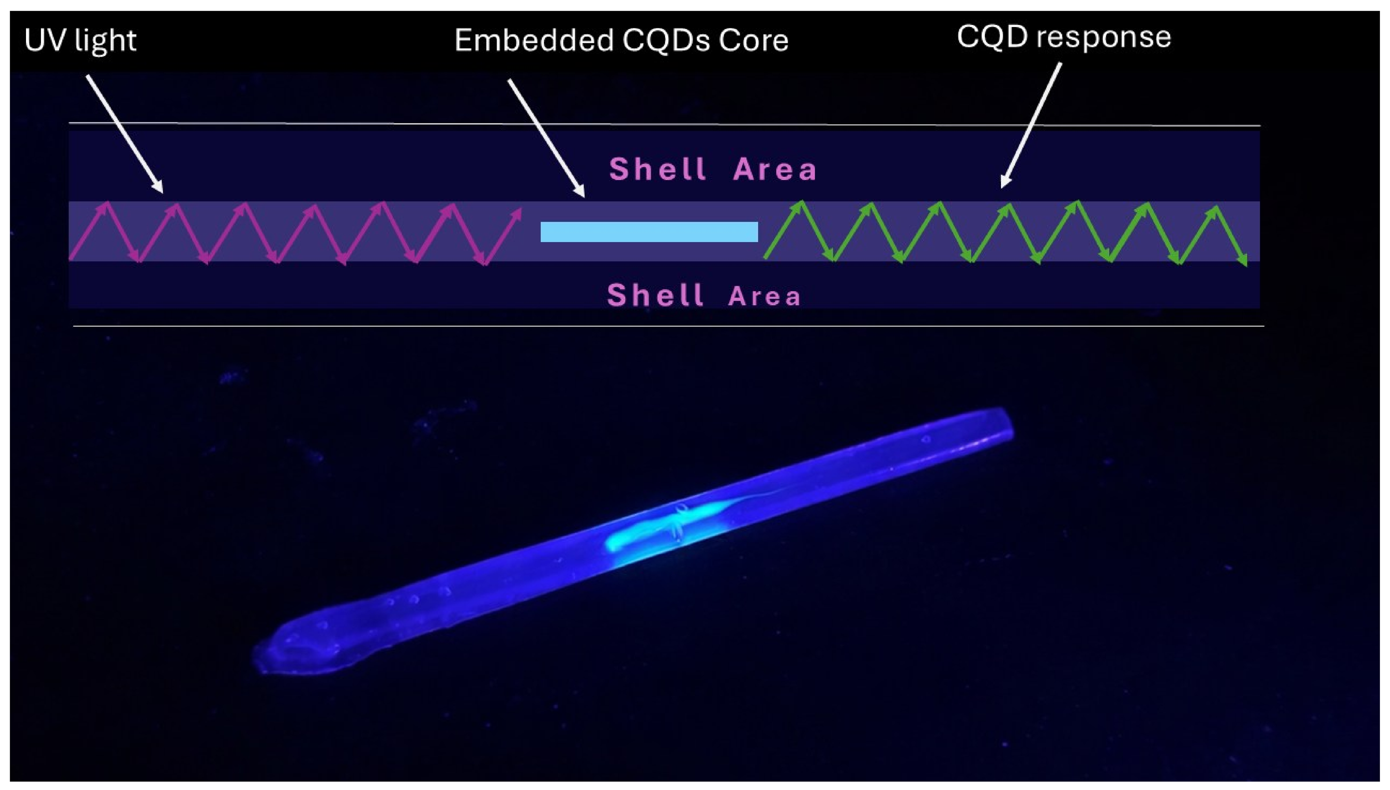

Figure 1 – Schematic of the CQD embedded core-shell waveguide, and fabricated waveguide under UV illumination.

Project Requirements

Quantum Dots	Must simultaneously print a waveguide with embedded quantum dots
Waveguide Capabilities	The waveguide must propagate light in the visible spectrum (380–750 nm)
Waveguide Quality	Core dimension along waveguide must not exceed a ± 0.01 mm tolerance
Sensor System	Must measure the sensor's response across 5°C-50°C and 0-10% strains independently with ± 0.1°C and ± 0.1% strain.
Optical Sensing	Must use an affordable COTS optical sensor capable of measuring QD emission wavelengths

Material/Geometry

Waveguide Geometry : The waveguide incorporates a multi-material core structure within a single-material shell.

- Verification: Cross-section measured using Keyence digital microscope (VHX-X1) (Figure 3).

Waveguide Materials:

- 3145 RTV Silicone - Shell & Core CQD region
  - High viscosity
  - Provides structural support
  - CQD compatible
- Sylgard 184 - Core
  - Excellent optical guiding
  - Not suitable for printing
  - CQD incompatible

Methods

Custom Nozzle:

- Triple-coaxial, core-shell
- Printed on Phrozen Sonic Mini 8K Resin Printer
- Allows for switching of core material
- Precise control of diameters

AM Methods:

- Hyrel Engine SR 3D Printer
- Pressure-controlled extrusion enables for precise core materials switching
- G-code allows precise control of length and location of CQD core

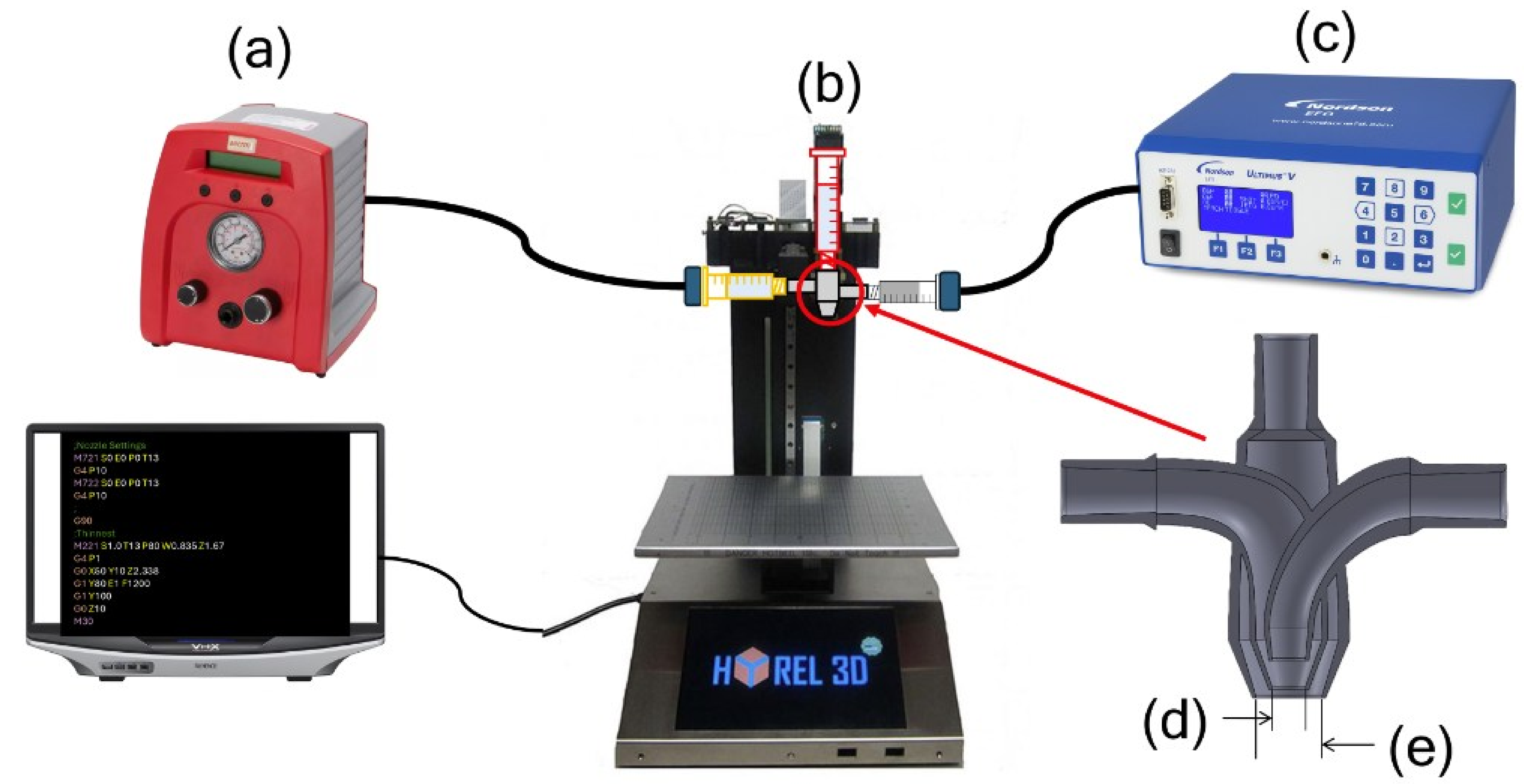

Figure 2 — Schematic of the additive manufacturing system setup: (a) LOCTITE Digital Syringe Dispenser, (b) Hyrel SDS 10 syringe pump, (c) Nordson Ultimus V High Precision Dispenser, (d) 3mm core nozzle, and (e) 6mm shell nozzle to ensure multimode optical propagation.

Test Setup:

- **Temperature Control**
  - Thermoelectric Cooler (TEC)
  - Arduino Nano with H-bridge PID control
  - PT100 for reference temperature
- **Optical Measurement**
  - Adafruit AS7341 Optical Spectrometer
    - measures intensity across discrete wavelength channels

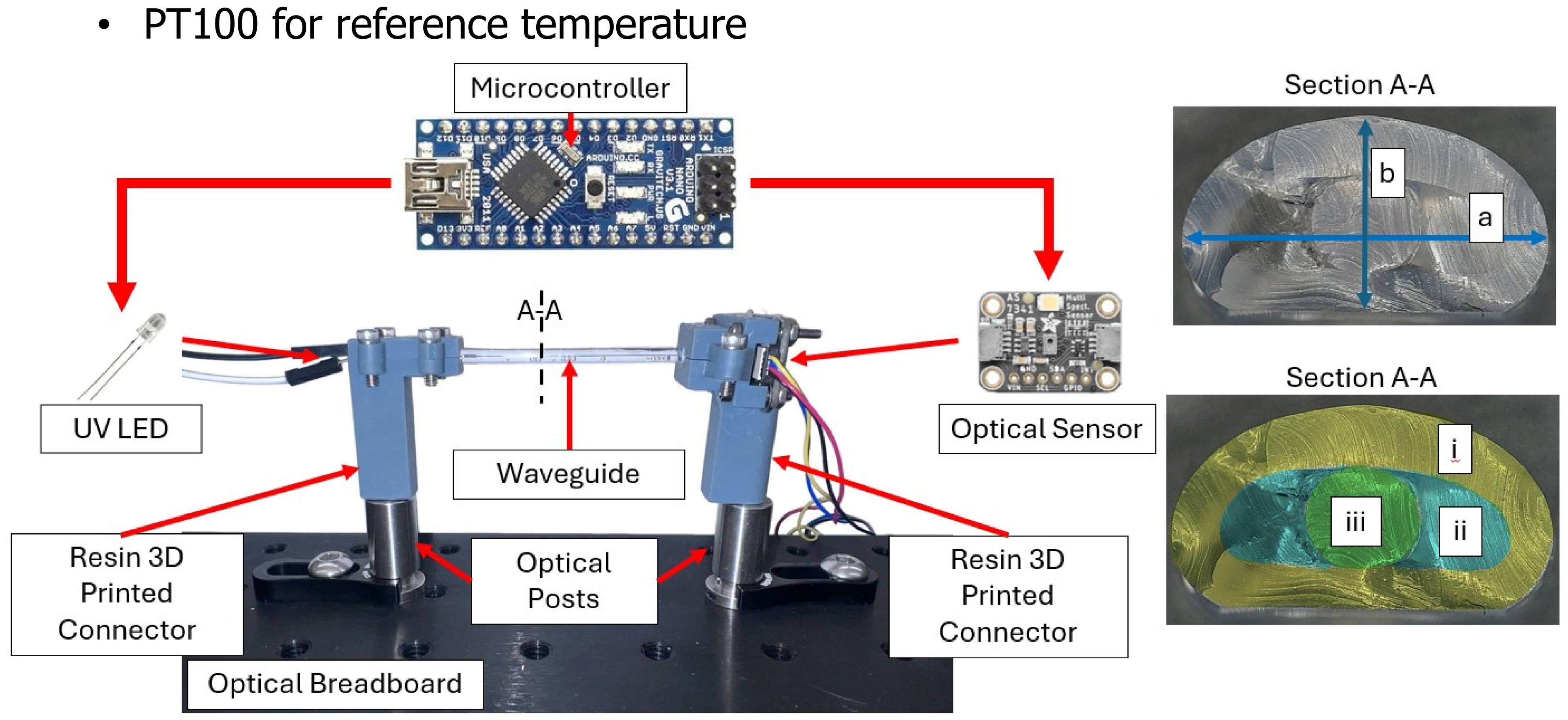

Figure 3 — Schematic of waveguide sensor system with cross-section views. The cross-sectional dimensions have an ellipticity of $a/b = 2.1 \pm 0.5$. Regions (i), (ii), and (iii) correspond to the RTV shell, Sylgard 184 core, and CQD–RTV core, respectively.

Results

Peak Wavelength Shift:

- Peak CQD emission wavelength shifts with increasing temperature
  - Matches known CQD temperature-dependent behavior
- Average peak emission: 260 ±30 counts
- With calibration, system achieves ± 1°C

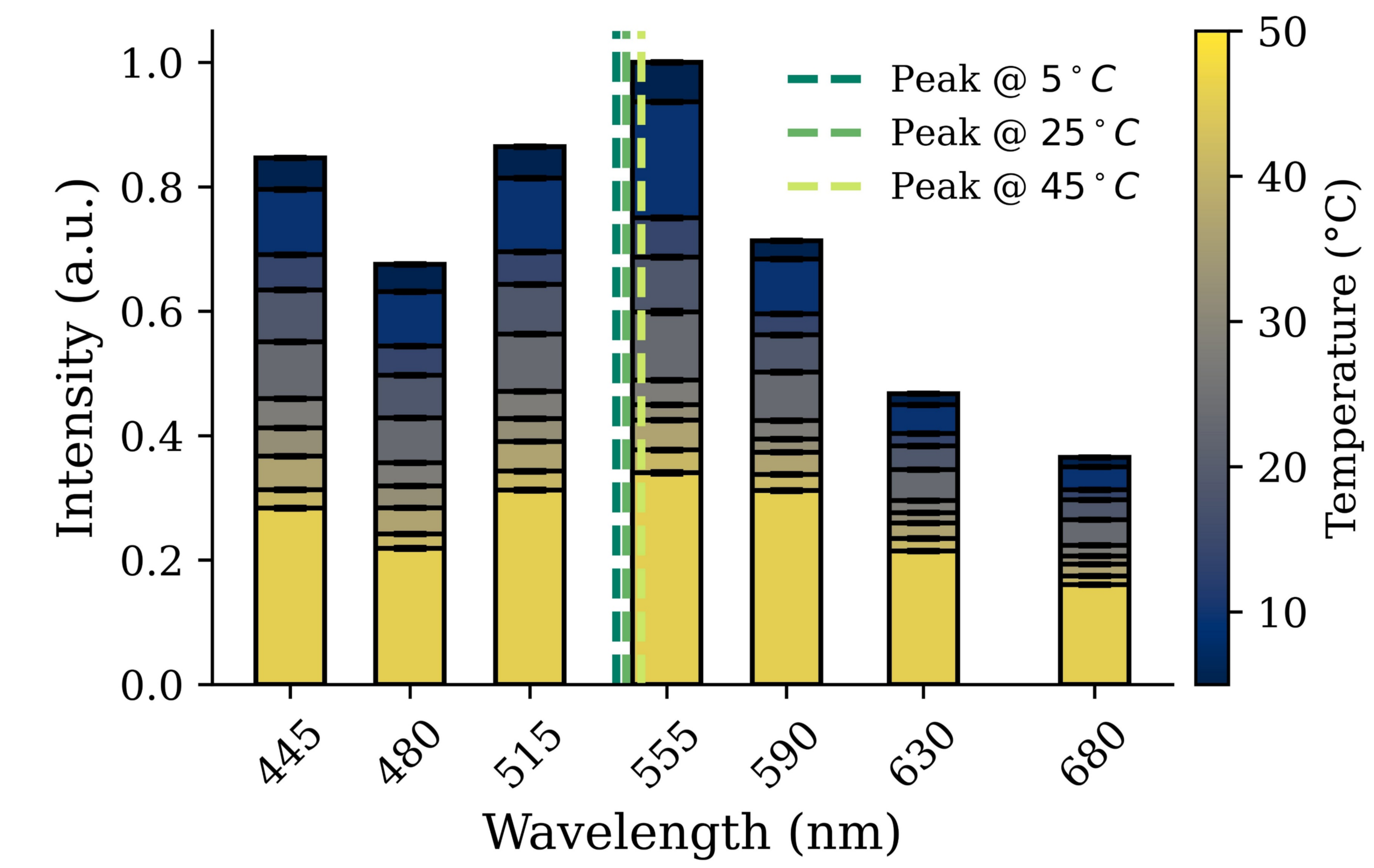

Figure 4 – intensity of light emission as function of temperature. Peak emission wavelength shown for chosen temperatures

Conclusion

- Low-cost solution: Unit cost of **$31.30** (optical spectrometer+ waveguide + excitation LED), significantly lower than traditional temperature sensing methods
  - e.g. Fiber Bragg Gratings~ $5,000-$10,000
- Versatile deployment: **Flexible** and **stretchable** waveguide enables use on diverse surfaces beyond laboratory settings
- Scalability: AM and customized nozzle allows for **varied lengths and geometries**
- Future potential: CQDs exhibit sensitivity to multiple stimuli (e.g., temperature and strain), enabling **multimodal sensing**

Future Work

Current System:

- Integrates CQDs in AM process
- Guides visible light
- Measures temperature via emission wavelength shifts
- Detects CQD emission spectra

Future Work:

- Optimize AM process to refine waveguide geometry
- Incorporate higher resolution CoTS sensors to enhance measurement precision
- Investigate CQD strain response

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